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Restoration Design for an Urban River: Some Lessons Learned

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Introduction

In an urban environment, the restoration of aquatic habitat features to rivers and streams can present unique challenges. Historic and current development activities typically result in changes to the stream, including alteration of alignment and cross-section, loss of flood plain, and changes in hydrologic and hydraulic conditions. In turn, these changes become constraints on the application of restoration techniques to these streams. Even with these constraints, a stream restoration project in an urban setting offers the opportunity to apply a variety of design techniques to improve aquatic habitat in channels that have been degraded by human activity. Once implemented, these projects also offer the opportunity to observe the performance of the restoration design techniques. Revisiting a restoration project in the years following stream modification can yield valuable insights that can then be applied to future restoration design projects.

In 1997, a project was completed on the Mad River in Waterbury, Connecticut to provide physical habitat enhancement measures in a previously altered reach of river. That project provides several lessons about the application of such restoration techniques in an urbanized setting.

The project involved reconstruction of previously altered river channel segments, partial removal of a dam structure, and provision of in-stream structural enhancements to support fish passage and aquatic habitat in river reaches that were and continue to be influenced by intensive urban conditions. In this case example, the habitat enhancements were implemented within an armored channel with no over-bank flood plain. The following discussion summarizes some observations regarding the success of the applied techniques, the long term performance of constructed fish passage and habitat features, the effects of other disturbance activities upstream of the restoration project area, problems with urban debris, and the establishment of riparian vegetation.

The underlying theme of this discussion is that observations of the long term performance of restoration techniques are of great value in understanding how to apply these techniques to the design of future projects. Successful restoration of rivers and streams in urban environments should therefore be based on experience gained in the urban environment.

Restoration of Mad River: An Overview of the Project

The Mad River is located in an intensively developed watershed and affected by historic alterations of the river channel and its flood plain. The river flows through the Brass Mill Center, a regional shopping center developed on the site of a former industrial mill complex in Waterbury, Connecticut. As typical of many industrial areas in New England, historic development had altered the natural alignment, cross section, bed form, riparian zone, and flood plain of the river. To respond to environmental permit requirements for the redevelopment of the site for the shopping center, the river was partially reconstructed, and measures were employed to enhance fisheries habitat along the affected water course.

In earlier papers, the author has described the design approach to implementing habitat enhancements in this river (Nyman 1998a, 1998b). The following briefly summarizes the design measures applied on the project.

The Mad River has a watershed of 67.6 square kilometers (26.1 square miles). Its mean annual average daily flow is 1.05 cubic meters per second (37 cubic feet per second). The 100-year return frequency flood flow for the segment under study is approximately 154.7 cubic meters per second (5465 cubic feet per second). Within the project area, past land use activities resulted in realignment of the channel throughout the industrial mill complex and other alterations, including (from downstream to upstream, within the study area):

- Entrainment of the river in an 335 m (1100-foot) long, multiple-barrel culvert;
- Confinement of a section of the river in a rectangular concrete channel 305 m (1000 feet) long; and
- Provision of a run-of-river dam that impounded a section of the river immediately upstream of this concrete-lined channel.

The redevelopment of the industrial site included remedial actions to remove contaminated site soils and river sediments, and the development of a regional commercial center. The project included the reconstruction and modification of this river channel. The following elements were included in this river reconstruction:

- Replacement of the culvert with a larger structure that incorporated a low flow barrel with provisions for fish passage. These measures included installation of baffles to control depths and velocities of flow, as well as construction of light-well openings to permit light penetration within the low-flow barrel of the structure;
- Removal of the concrete-lined channel, and construction of a new riprap-lined channel in an altered alignment;
- Partial removal of the run-of-river dam and provision of habitat structure and fish passage measures in the modified pool. Improvements included reshaping and stabilization of embankments along the former pool and restoration of substrate within the pool area; and
- Provision of a number of physical features within these stream segments to enhance fisheries habitat.

The stream gradient, lack of historic flood plain, and other site constraints required reconstruction of the channel in a riprap-lined, trapezoidal cross-section. Stone was installed with aggregate bedding or with grout, depending on side slopes and hydraulic conditions. Thus, neither the existing nor the new river geometry was completely based on "natural channel design" principles. However, the restoration design team developed habitat enhancement features given the modified channel "template." Furthermore, as the channel was designed to convey runoff from a highly urbanized watershed without over-bank flooding, the design of the habitat enhancements needed to address a wide range of base- and flood-flow conditions.

The design applied a number of in-stream structural improvements to promote the development of biological habitat within the disturbed channel. In addition, the design addressed provision of riparian vegetation along the channel and installation of measures to facilitate the passage of fish at obstructions. The stream reconstruction project included the following measures:

- Installation of wing deflectors, vortex rock weirs, and random boulder placements to promote pool/riffle development and provide habitat structure within the reconstructed stream bed;
- Construction of a low-flow channel (an artificial thalweg) within the design cross-section of the reconstructed stream. This thalweg design provides for a minimum depth and velocity of flow during low flow periods;
- Placement of granular substrate materials in the void spaces of rock in the modified channel sections. Granular materials were specified based on analysis of substrate composition in less-disturbed river channel reaches upstream and downstream of the reconstruction area;
- Plantings within the void spaces in riprap bank lining material, to promote the development of riparian vegetation. Plantings were also proposed near the top of the reconstructed bank to provide for shade and terrestrial habitat;
- Installation of boulder/slot fishways (based on the design principles of a "vertical slot" fishway, see Nyman, 1998b) to allow for fish passage at the partially removed dam and a steep-gradient channel segment remaining at the inlet end of the former impoundment.

Project design occurred in 1995-1996. Construction of the river relocation and channel improvements was completed in 1997. Project permits did not require a formal monitoring program following project completion. The author has conducted periodic observations of the restoration project since that time to confirm that the installed improvements have remained generally stable (with some exceptions as discussed below) and functional. However, these observations provide some interesting lessons about the application of the selected design measures.

Restoration of Mad River: Some Lessons Learned

The following is a capsule description of some of the lessons derived from observations of the reconstructed Mad River channel at the Brass Mill Center.

Lesson #1: A Variety of Restoration Design Techniques are Adaptable to the Urban Setting

Design approaches for restoration can be drawn from "natural channel design" methods, traditional hydraulic engineering techniques (such as traditional tractive stress and other methods for analyzing stone sizes for channel lining), and methodologies from other disciplines to develop workable solutions for the urban river channel. Some interesting examples from this project include:

- Traditional rock sizing methods can be used for habitat feature design. Within the study area, historic development has reduced or eliminated the functional flood plain of Mad River. Flood flows up to the 100-year event are confined to the channel. The design of habitat structures therefore must account for depths and velocities of flood flows conveyed by the channel. The design used traditional riprap sizing methods and empirical data on "pick-up" velocities to determine stone size for habitat structures and bed and bank lining material. These stone sizes are likely larger than would be found under natural conditions absent the urban development. However, providing the larger stone size was necessary for stability of the habitat features fabricated using cobbles and boulders. The habitat features constructed using this stone-sizing approach have remained stable and contribute to the diversity of bed structure and the development of pool/riffle sequence, as intended by the original design.

- Hydraulic design methods can be adapted to natural materials. The project included the design of fishways using natural materials. The fishway design adapts the principles of a vertical slot fishway (Nyman, 1998b). This fish passage structure consists of a series of small pools constructed using boulders, separated by slotted weirs also fabricated using boulders and cobbles. Conventional hydraulic design methods were used to estimate velocities through these structures, applying some judgment in the selection of weir or orifice dimensions and hydraulic coefficients (the team found no design charts for boulder weirs). The estimated velocities fell within the range permissible for fish species of concern on this project (blue-back herring, 1.2 to 2.4 m/sec, 4.0 to 8.0 feet per second). Following construction, field measurements at the structures during a full-flow event documented that actual velocities were within the predicted range. This suggests that with some judgment, as well as corroboration by alternative estimating procedures, hydraulic design methods that are typically used for engineered structures (i.e., concrete and steel) can also be used for natural materials with a reasonable degree of confidence.

- Design methods can be borrowed from other disciplines. The project included the reconstruction of a 335-meter (1100-foot) long culvert to provide greater flood conveyance capacity, and to provide a low-flow barrel designed for fish passage. In addition to providing baffles to control flow depths and velocities, the design included openings in the top of the culvert to permit penetration of light for a nominal level of illumination at the floor of the culvert barrel. Techniques for the design of skylights were adapted from lighting engineering practices to estimate the size and spacing of light wells extending to final grade above the culvert. In this way, the project design reached beyond the usual disciplines associated with culvert design, to address the design problem of achieving sufficient illumination for fish passage.

Lesson #2: Stream restoration decisions must consider other activities in the watershed.

River restoration must be undertaken with an understanding of the river watershed. This understanding must include knowledge of watershed hydrology, existing and anticipated land uses, sources and quantities of external sediment inputs, and other factors. In addition to these factors, major decisions affecting hydrology, sediment load, and other factors affecting river morphology may occur independently in an urban watershed. The design of a restoration project should not only address the existing conditions in the watershed, but also explore the potential for major changes anticipated in the watershed, such as dam removals, major short-term changes in land use, long-term growth of development, and large construction projects that could significantly affect sediment load to the river system.

Other activities occurring in the watershed outside of the immediate boundaries of the restoration project can significantly influence the outcome of a restoration effort. The following examples will illustrate this point:

- Removal of dams outside the project area can be problematic. The Mad River restoration at the Brass Mill Center appeared to successfully function as designed during the initial months following its construction. However, subsequent to project completion, less than a mile upstream of the project area, a separate project resulted in partial removal of a second dam. The spillway removal dewatered the upstream impoundment. In addition, the landowner allowed construction fill to be placed in a portion of the exposed bottom of the former pool. The dam removal project also included reestablishing part of the upstream river channel with a riprap-lined channel, but left untreated the remaining historic channel within the former impoundment limits. These activities resulted in an unstable channel that has eroded both the newly exposed river bed and the deposited fill, and delivered this sediment load to the river downstream of the breached dam. These sediments have in turn redeposited throughout the river restoration project described in this paper, particularly within pools that were developed in the reconstructed channel.

  The decision to breach the off-site dam was implemented independently of the river restoration project. To ensure the most successful restoration effort, these two projects should have been coordinated. The design of the dam removal should have properly addressed sediment impacts. If the activities had been coordinated, the design of the river enhancement measures could have addressed the changes in hydraulic and sediment conditions anticipated for such a dam removal.

  In an urban watershed, major decisions affecting hydrology, sediment load, and other factors affecting river morphology may occur independently. The design of a restoration project should not only address the existing conditions in the watershed, but also explore the potential for major changes anticipated in the watershed, such as dam removals, major short-term changes in land use, long-term growth of development, and large construction projects that could significantly affect sediment load to the river system.

- Restoration design should account for urban debris. The design of the project included the fishway structure described above, fabricated using boulders and incorporating the use of stone weirs located in narrow slots between the resting pools. The narrow slots have proven susceptible to clogging by urban debris. The “bed load” in this urban river includes shopping carts, tires, mattresses and box springs, discarded plywood, and other debris that can easily become entangled in a narrow opening such as a fishway entrance, and interfere with the function of the structure. Furthermore, field observations have noted evidence that unknown individuals have intentionally placed boards, mattresses, and other discarded materials in the slots in an effort to obstruct flows through these openings. This suggests that future efforts to provide fishways in urban streams should consider alternative designs (such as rock ramp fishways) that do not involve narrow weirs or other features that are subject to vandalism or easily obstructed by urban debris. Also, the restoration of urban streams may need to include provision for ongoing maintenance, where debris accumulation may interfere with the post-construction performance of the restoration measures and other hydraulic structures.

Lesson #3: Restored urban rivers are potential reference models for future restoration projects.

River restoration designers should observe natural response to other human interventions in river channels, to learn of techniques that might be applied to future restoration projects. If reference models are needed for restoring urban river channels, such references may be found in other urban river channels that exhibit desirable habitat features and functions. Such features may reflect a natural system response to the conditions imposed by channel disturbance, channel reconstruction, and other urban activities.

While the off-site dam removal project described above produced negative impacts associated with sediment delivered to the restored downstream river channel, this occurrence provided some positive lessons as well. The restoration design included two measures that showed unanticipated benefits that helped offset some of the effects of the sediment deposition.

In addition, observations made on this project confirm that riparian vegetation can be established in riprap-lined stream embankments. These findings are discussed further below:

- Wing deflectors contribute to channel recovery following sedimentation. The Mad River restoration included installation of wing deflectors comprising large boulder perimeters with cobble infill. A number of these wing deflectors were constructed in a shallow pool located upstream of a former dam within the project area, which was breached as part of the project. Sediment from the off-site dam removal ended up filling much of this pool. Subsequent river flows have reshaped this sediment, and a new sinuous channel has developed in the deposited sediment. The wing deflectors within this pool, though partially buried in sediment, appear to provide sufficient constriction of the river cross-section that they are reinforcing the development of this new low-flow channel. These structures are contributing to the transport of the excess sediment load through this section of the river and the establishment of more natural channel morphology. Thus, the wing deflectors appear to be assisting a natural process of channel recovery following the excessive sedimentation event.

- An artificial thalweg can also contribute to channel recovery following sedimentation. The design also provided for an artificial thalweg in one reach of the reconstructed section of the river. The Mad River under natural conditions would have a boulder/cobble bed formed in glacial till, and would likely not have a well-defined thalweg. However, the design provided for a “pilot channel” in the reconstructed cross-section for two reasons. First, low flows in the urbanized watershed tend to be extremely small, and the confined channel would provide for a minimum depth of flow during late summer low-flow periods. Second, the confined channel could be designed so that velocities within the pilot channel just flowing full would be on the order of 0.3 to 0.6 m/sec (1.0 to 2.0 feet per second), which helps flush the stream substrate and maintain conditions suitable for benthic organisms (Wesche, 1985).

Subsequent to the sediment release from the off-site dam removal, the author has observed that where this artificial thalweg was provided, the sediment deposition has been minimal. The thalweg appears to be maintaining a well-flushed low flow channel, proving to be "self-cleaning" relative to the unanticipated sediment load. This observation suggests the use of such an artificial thalweg on other restoration projects in urban settings where the projected sediment load from the watershed may be unpredictable.

- Riparian vegetation can be established in riprap. From observations of previously reconstructed river embankments at various New England sites, the restoration design team concluded that riprap armored channel banks often support the colonization of herbaceous and woody plant species. Void spaces in the stone trap sediment during high flow events and this sediment provides a medium for plant colonization. Based on these observations, the Mad River restoration project included provisions for planting the proposed stone-lined channel banks. The design specified placement of organic planting media in the stone voids and installation of a selection of indigenous plant species.

  During construction, the landowner did not install all of the required plantings. After several years, however, the rock-lined embankments now support a healthy growth of vegetation. This vegetation consists of species that have naturally colonized the riprap channel lining. This reinforces the previous observations that riprap channels support riparian vegetation, and that plantings in riprap would be a viable restoration strategy. While allowing natural colonization may be an option, intensive planting as part of embankment construction would help establish desirable plant species and thereby preempt colonization by undesirable non-native invasive species.

Conclusion

The Mad River restoration project required provision of habitat improvements within an engineered "template" for the river. The restoration design team provided physical habitat features within a riprap-lined trapezoidal channel designed to convey flows without over-bank flooding up to the 100-year frequency event. Such a design template constrained the opportunity to apply "natural channel design" principles. However, the restoration team learned during the design process, and confirmed by subsequent observations of the completed project, that a variety of techniques can be adapted to achieve a naturalized stream bed within a reconstructed urban channel.

The historic development of an urban watershed and activities within and near the river result in alterations of the natural channel alignment and cross-section, filling and development in the flood plain, changes in land use that affect watershed hydrology and thus the flow regime of the river, and disturbance of soil that affects sediment loading of the watercourse. Activities in the watershed, including dam removal, significant alterations in land use, and exposure of soils by major construction projects, can result in significant impacts to a reach of river under consideration for restoration. In turn, these changes impose constraints on the application of restoration techniques to urban rivers.

Loss of flood plain areas, channel constriction by adjacent development, changes in hydraulic characteristics at bridge and culvert crossings, and changes to base flows and storm flows from the developed watershed, result in a river resource that significantly differs from the natural channel that once occupied its valley. The changes induced by urban development can result in loss of habitat diversity, problems with fish passage, accelerated aggradation or degradation of the stream bed, changes in temperature regime, and other conditions that degrade habitat function. The restoration of an urban river to its original condition is rarely, if ever, possible because urban activities permanently alter the landscape.

However, partial restoration in the form of habitat enhancements may be achieved, if the constraints imposed by the altered environment are recognized. Addressing these constraints requires adapting design techniques, accounting for other watershed activities, evaluating the sustainability of design measures, and considering maintainability in the urban setting.

Rivers in urban settings should be considered as potential reference models for the restoration of urban rivers. Observing the long-term performance of river restoration techniques in the urban setting can offer valuable insights as to which techniques are adaptable and successful for enhancing habitat in rivers that have been influenced by intensive development activity. Each restoration project provides an opportunity to evaluate the success of the techniques applied, monitor natural system response to the restoration activity, and refine the methodologies used to achieve naturalized channel design.

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